WE CLAIM:

1. A pump-less anti-lock brake apparatus for controlling the rotational speeds, during a braking cycle, of only the rear brakes of a vehicle having at least one front and one rear wheel and front and rear brakes acting on the front and rear wheels respectively, the apparatus comprising:

a rear brake hydraulic circuit including a master cylinder for supplying a volume of pressurized brake fluid to the rear brakes during the braking cycle, a fluid storage element, and a rear brake pressure control (RPC) apparatus;

the RPC apparatus including a hydraulic control unit (HCU) and an electrical control unit (ECU), with the HCU operatively connecting the master cylinder to the rear brakes and the fluid storage element for controlling fluid pressure applied to the rear brakes during the braking cycle and fluid flow to the fluid storage element, and the ECU operatively connected to the HCU for controlling the HCU as a function of the rotational speeds of the at least one front and one rear wheel.

2. The brake apparatus of claim 1 wherein the RPC apparatus further includes:

a first wheel speed sensor operatively connected for sensing a speed of the at least one front wheel and sending a front wheel speed signal to the ECU; and

a second speed sensor operatively connected for sensing a speed of the at least one rear wheel and sending a rear wheel speed signal to the ECU.

3. The brake apparatus of claim 2 wherein the vehicle includes more than one front wheel, the first wheel speed sensor is connected to one of the front wheels; and the RPC apparatus further includes a third wheel sensor connected to one of the other front wheels for sensing the speed of the other front wheel.

4. The brake apparatus of claim 1 wherein the function of rotational speed used by the ECU for controlling the HCU includes:

calculating a vehicle speed (VS Est) as a function of the front wheel speed; and

comparing the rotational speed of the rear wheel to the vehicle speed.

5. The brake apparatus of claim 1 wherein the ECU further controls the HCU as a function of the fluid flow to the fluid storage element during the braking cycle.

6. The brake apparatus of claim 1 wherein the ECU further controls the HCU as a function of a net fluid flow to the fluid storage element during the braking cycle and prior to a subsequent braking cycle.

7. The brake apparatus of claim 1 wherein the master cylinder includes a movable piston for supplying the volume of pressurized brake fluid to the rear brake hydraulic circuit, and the control system further includes a brake apply position sensor operatively connected between the piston and the ECU for sensing a position of the piston and supplying a piston position signal to the ECU.

8. The brake apparatus of claim 2 wherein the HCU includes:

a normally open apply valve operatively connected to the ECU to be controlled thereby, and having an inlet connected to the master cylinder for receiving pressurized fluid therefrom and an outlet connected to the rear brakes; and

a normally closed release valve operatively connected to the ECU to be controlled thereby, and having an inlet connected to the rear brakes for receiving fluid therefrom and an outlet connected to the fluid receiving element.

9. The brake apparatus of claim 8 wherein the ECU calculates a net flow of fluid to the fluid storage element during the braking cycle as a function of an amount of time that the release valve is open during the braking cycle.

10. The brake apparatus of claim 9 wherein:

the ECU terminates anti-lock control of the rear brakes and returns the apply and release valves to their respective normally open and normally closed states when a predetermined net flow of fluid to the fluid storage is calculated.

11. The brake apparatus of claim 8 further including:

a first check valve operatively connected between the inlet and outlet of the apply valve, for blocking fluid flow from the inlet to the outlet of the apply valve, and for passage of flow from the outlet to the inlet of the apply valve; and

a second check valve operatively connected between the inlet and outlet of the release valve, for blocking fluid flow from the inlet to the outlet of the release valve, and for passage of flow from the outlet to the inlet of the release valve.

12. The brake apparatus of claim 8 wherein the fluid receiving unit is an accumulator.

13. The brake apparatus of claim 12 wherein:

the ECU calculates a net flow of fluid to the fluid storage element during the braking cycle as a function of an amount of time that the release valve is open during the braking cycle;

the ECU calculates a net flow of fluid from the fluid storage element subsequent to the braking cycle; and

modifies its control function to reduce pressure during a subsequent braking cycle if all of the fluid has not exited the fluid storage element prior to initiation of the subsequent braking cycle.

14. The brake apparatus of claim 13 wherein:

the ECU terminates anti-lock control of the rear brakes and returns the apply and release valves to their respective normally open and normally closed states when a predetermined net flow of fluid to the fluid storage is calculated.

15. The brake apparatus of claim 12 wherein the rear brake hydraulic circuit further includes a proportioning valve operatively connected between the rear brake circuit and the front brakes.

16. The brake apparatus of claim 8 wherein the fluid receiving element is a fluid reservoir supplying fluid to the master cylinder.

17. The brake apparatus of claim 16 further including a fluid level sensor operatively connected for sensing a level of the fluid in the reservoir and sending a signal to the ECU indicative of the level of the fluid in the reservoir.

18. The brake apparatus of claim 8 wherein the vehicle includes a drivetrain having a transmission for supplying motive power to the rear wheels and the second speed sensor is operatively connected for sensing a speed of an element of the transmission.

19. The brake apparatus of claim 8 wherein the vehicle includes a drivetrain having a differential for supplying motive power to the rear wheels and the second speed sensor is operatively connected for sensing a speed of an element of the differential.

20. The brake apparatus of claim 8 wherein the HCU is mounted on the master cylinder.

21. The brake apparatus of claim 20 wherein the ECU is mounted on the master cylinder.

22. The brake apparatus of claim 20 wherein:

the master cylinder includes a threaded port for connecting the master cylinder to the rear brake hydraulic system; and

the HCU includes an internal passage connected to the inlet of the inlet valve, and the HCU is mounted on the master cylinder with a hollow fastener extending through the internal passage of the HCU and engaging the threaded port;

the hollow fastener having an internal bore providing fluid communication with the master cylinder and a cross-drilled hole intersecting the internal bore for passage of fluid to and from the internal passage of the HCU.

23. The brake apparatus of claim 22 wherein the ECU is mounted on the HCU.

24. The brake apparatus of claim 22 wherein the fluid receiving element is an accumulator disposed in the HCU in fluid communication with the outlet of the release valve.

25. The brake apparatus of claim 24 wherein the ECU is mounted on the HCU.

26. The brake apparatus of claim 22 wherein the fluid receiving element is a fluid reservoir mounted on the master cylinder for supplying fluid to the master cylinder, and the outlet of the release valve is connected in fluid communication with the fluid reservoir.

27. The brake apparatus of claim 26 wherein the ECU is mounted on the HCU.

28. The brake apparatus of claim 26 wherein:

the fluid reservoir includes a hose connection snorkel for passage of fluid to and from the fluid reservoir;

the HCU includes a hose connection snorkel in fluid communication with the outlet of the release valve of the HCU; and

a hose connects the snorkels on the HCU and the fluid reservoir.

29. The brake apparatus of claim 28 wherein the ECU is mounted on the HCU.

30. A rear brake pressure control (RPC) apparatus for a rear brake hydraulic circuit including a fluid storage element and a master cylinder supplying a volume of pressurized brake fluid to the rear brakes during the braking cycle in a pump-less anti-lock brake apparatus controlling the rotational speeds, during a braking cycle, of only the rear brakes of a vehicle having at least one front wheel and at least one rear wheel, and front and rear brakes acting on the front and rear wheels respectively, the RPC apparatus comprising:

a hydraulic control unit (HCU) operatively connecting the master cylinder to the rear brakes and the fluid storage element for controlling fluid pressure applied to the rear brakes during the braking cycle and fluid flow to and from the fluid storage element; and

an electrical control unit (ECU) operatively connected to the HCU for controlling the HCU as a function of the rotational speeds of at least one front and one rear wheel.

31. The RPC apparatus of claim 30 further comprising:

a first wheel speed sensor operatively connected for sensing a speed of one of the at least one front wheels and sending a front wheel speed signal to the ECU; and

a second speed sensor operatively connected for sensing a speed of at least one of the at least one rear wheels and sending rear wheel speed signal to the ECU.

32. The RPC apparatus of claim 31 wherein the vehicle includes at least one left and one right front wheel:

the first wheel speed sensor is connected to one of the left or right front wheels; and

the RPC apparatus further comprises a third wheel sensor connected to the other of the left and right front wheels for sensing the speed of the other of the left and right front wheels.

33. The RPC apparatus of claim 30 wherein the master cylinder includes a movable piston for supplying the volume of pressurized brake fluid to the rear brake hydraulic circuit, and the RPC apparatus further includes a brake apply position sensor operatively connected between the piston and the ECU for sensing a position of the piston and supplying a piston position signal to the ECU.

34. The RPC apparatus of claim 30 wherein the HCU includes:

a normally open apply valve operatively connected to the ECU to be controlled thereby, and having an inlet connected to the master cylinder for receiving pressurized fluid therefrom and an outlet connected to the rear brakes; and

a normally closed release valve operatively connected to the ECU to be controlled thereby, and having an inlet connected to the rear brakes for receiving fluid therefrom and an outlet connected to the fluid receiving element.

35. The RPC apparatus of claim 30 wherein the fluid receiving unit is an accumulator disposed in the HCU.

36. The RPC apparatus of claim 30 wherein the fluid receiving element is a fluid reservoir supplying fluid to the master cylinder.

37. The RPC apparatus of claim 36 further including a fluid level sensor operatively connected for sensing a level of the fluid in the reservoir and sending a signal to the ECU indicative of the level of the fluid in the reservoir.

38. The RPC apparatus of claim 34 wherein the rear brake pressure control unit is mounted on the master cylinder.

39. The RPC apparatus of claim 38 wherein:

the master cylinder includes a threaded port for connecting the master cylinder to the rear brake hydraulic system; and

the HCU includes an internal passage connected to the inlet of the apply valve, and the HCU is mounted on the master cylinder with a hollow fastener extending through the internal passage of the HCU and engaging the threaded port;

the hollow fastener having an internal bore providing fluid communication with the master cylinder and a cross-drilled hole intersecting the internal bore for passage of fluid to and from the internal passage of the HCU.

40. The RPC apparatus of claim 38 wherein the fluid receiving element is an accumulator disposed in the HCU in fluid communication with the outlet of the release valve.

41. The RPC apparatus of claim 39 wherein the fluid receiving element is a fluid reservoir mounted on the master cylinder for supplying fluid to the master cylinder, and the outlet of the release valve is connected in fluid communication with the fluid reservoir.

42. The RPC apparatus of claim 41 wherein:

the fluid reservoir includes a hose connection snorkel for passage of fluid to and from the fluid reservoir;

the HCU includes a hose connection snorkel in fluid communication with the outlet of the release valve; and

a hose connects the snorkels on the HCU and the fluid reservoir.

43. A method for controlling a rear brake hydraulic circuit having a fluid storage element and a master cylinder supplying a volume of pressurized brake fluid to the rear brakes during the braking cycle in a pump-less anti-lock brake apparatus controlling the rotational speeds, during a braking cycle, of only the rear brakes of a vehicle having at least one front wheel, at least one rear wheel, and front and rear brakes acting on the front and rear wheels respectively, the method comprising:

controlling fluid pressure and flow from the master cylinder applied to the rear brakes during the braking cycle and fluid flow to and from the fluid storage element as a function of the rotational speeds of at least one front and one rear wheel.

44. The method of claim 43 further comprising:

blocking the flow of pressurized fluid to the fluid receiving element prior to detecting an impending lock up of the rear brakes; and

controlling the fluid pressure in the rear brake circuit only after detecting an impending lock up of the rear brakes.

45. The method of claim 43 wherein the function of rotational speed used by the ECU for controlling the fluid pressure applied to the rear brakes comprises:

determining a reference speed of the vehicle from the rotational speeds of the at least one front wheel; and

comparing the rotational speed of the rear wheel to the reference vehicle velocity for detecting a slippage of the rear wheels.

46. The method of claim 43 further comprising controlling the fluid pressure applied to the rear brakes as a function of fluid flow to the fluid storage element during the braking cycle.

47. The method of claim 46 comprising returning fluid in the fluid receiving element to the rear brake circuit following completion of the braking event.

48. The method of claim 47 further comprising controlling the fluid pressure applied to the rear brakes as a function of a net fluid flow to the fluid storage element during the braking cycle and prior to a subsequent braking cycle.

49. The method of claim 43 further comprising:

connecting an inlet of a normally open apply valve to the master cylinder for receiving pressurized fluid therefrom, and connecting an outlet of the normally open apply valve to the rear brakes;

connecting an inlet of a normally closed release valve to the rear brakes for receiving fluid therefrom, and connecting an outlet of the normally closed release valve to the fluid receiving element; and

controlling fluid pressure applied to the rear brakes during the braking cycle and fluid flow to and from the fluid storage element by selectively opening and closing the apply and release valves as a function of the rotational speeds of at least one front and one rear wheel.

50. The method of claim 49 further comprising calculating a net flow of fluid to the fluid storage element during the braking cycle as a function of an amount of time that the release valve is open during the braking cycle.

51. The method of claim 50 further comprising terminating anti-lock control of the rear brakes and returning the apply and release valves to their respective normally open and normally closed states when a predetermined net flow of fluid to the fluid storage is calculated.

52. The method of claim 43 wherein the vehicle is operable in a four-wheel drive mode, and the method further comprises inhibiting control of both the fluid pressure applied to the rear brakes during the braking cycle and the fluid flow to and from the fluid storage element as a function of the rotational speeds of at least one front and one rear wheel, while the vehicle is operating in the four wheel drive mode.

53. A method for providing rear pressure control (RPC) for controlling a rear brake hydraulic circuit having a fluid storage element and a master cylinder supplying a volume of pressurized brake fluid to the rear brakes during the braking cycle in a pump-less anti-lock brake apparatus controlling the rotational speeds, during a braking cycle, of only the rear brakes of a vehicle having at least one front wheel, at least one rear wheel, and front and rear brakes acting on the front and rear wheels respectively, the method comprising:

monitoring the front wheel speed;

monitoring the rear wheel speed;

calculating a vehicle speed (VS Est) as a function of the front wheel speed;

calculating an RPC entry point as a function of vehicle speed (VS Est);

calculating an RPC term as a function of vehicle speed and rear wheel speed; and

controlling the rear brake circuit as a function of the RPC term and RPC entry point.

54. The method of claim 53 further comprising:

determining a road surface condition; and

modifying the RPC entry point as a function of the road surface condition.

55. The method of claim 54 comprising determining the road surface condition as a function of variations in at least one of the front and rear wheel speeds.

56. The method of claim 53 wherein the RPC term is calculated as the proportional and derivative difference between VS Est and the rear wheel speed.

57. The method of claim 53 further comprising controlling the rear brake circuit to provide dynamic rear proportioning (DRP) of brake pressure supplied by the master cylinder.

58. The method of claim 57 wherein DRP is provided as a function of front wheel speed.

59. The method of claim 58 further comprising calculating a DRP term as a proportional and derivative difference between the front wheel speed and the rear wheel speed.

60. The method of claim 59 further comprising calculating a DRP entry point as a function of the vehicle speed estimate (VS Est).

61. The method of claim 53 further comprising controlling the rear brake circuit as a function of a predetermined volume of fluid supplied by the master cylinder during the braking cycle.

62. The method of claim 53 further comprising controlling the rear brake circuit as a function of a flow of fluid to the fluid storage device.

63. A method for providing dynamic rear proportioning (DRP) for controlling a rear brake hydraulic circuit having a fluid storage element and a master cylinder supplying a volume of pressurized brake fluid to the rear brakes during the braking cycle in a pump-less anti-lock brake apparatus controlling the rotational speeds, during a braking cycle, of only the rear brakes of a vehicle having at least one front wheel, at least one rear wheel, and front and rear brakes acting on the front and rear wheels respectively, the method comprising:

monitoring the front wheel speed;

monitoring the rear wheel speed;

calculating a vehicle speed (VS Est) as a function of the front wheel speed;

calculating a DRP entry point as a function of vehicle speed (VS Est);

calculating a DRP term as a function of front wheel speed and rear wheel speed; and

controlling the rear brake circuit as a function of the DRP term and DRP entry point.

64. The method of claim 63 further comprising calculating the DRP term as a proportional and derivative difference between the front wheel speed and the rear wheel speed.

65. The method of claim 63 further comprising providing rear pressure control (RPC) of the rear brake circuit.

66. The method of claim 65 further comprising:

calculating an RPC entry point as a function of vehicle speed (VS Est);

calculating an RPC term as a function of vehicle speed and rear wheel speed; and

controlling the rear brake circuit as a function of the RPC term and RPC entry point.

67. The method of claim 66 wherein the RPC term is calculated as the proportional and derivative difference between VS Est and the rear wheel speed.

68. The method of claim 66 further comprising:

determining a road surface condition; and

modifying the RPC entry point as a function of the road surface condition.

69. The method of claim 68 comprising determining the road surface condition as a function of variations in at least one of the front and rear wheel speeds.

70. The method of claim 63 further comprising controlling the rear brake circuit as a function of a predetermined volume of fluid supplied by the master cylinder during the braking cycle.

71. The method of claim 63 further comprising controlling the rear brake circuit as a function of a flow of fluid to the fluid storage device.